

Electronically-Steerable, Coherent Laser Arrays

REALLY Small, Lightweight, High Power Lasers for DoD Applications



MTO Symposium
Joseph Mangano, PM
March 7, 2007

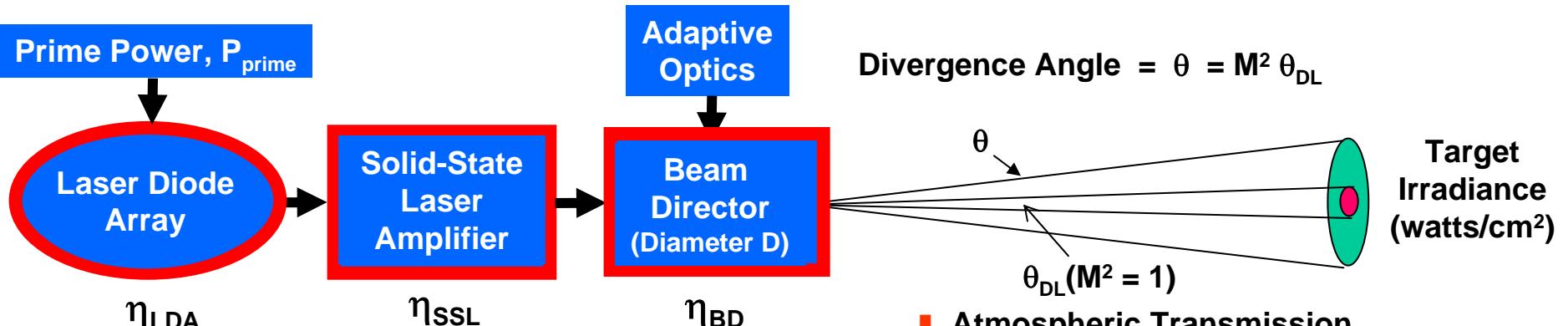
Report Documentation Page

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Diode-Pumped, Solid-State Laser Systems



- **Power Delivery Efficiency** $\sim \frac{\eta_{\text{LDA}} \eta_{\text{SSL}} \eta_{\text{BD}}}{M^4}$

- **Challenges**

- Power Scaling
- Efficiency
- Beam Quality
- Size and Weight
- Lifetime/Reliability
- Electronically-steered, Conformal, Adaptive, Optical Phased Arrays

Technologies:

- Electronically-Steered, Optical Phased Arrays driven by:
 - Fiber Laser Amplifiers (APPLE)
- or directly by:
 - Coherent Laser Diode Arrays (COCHISE)

Challenge: Electronically-Steered 100 kW Laser System at 2 kg per kilowatt



APPLE Laser Beam Directors

Adaptive Photonic Phase-Locked Elements

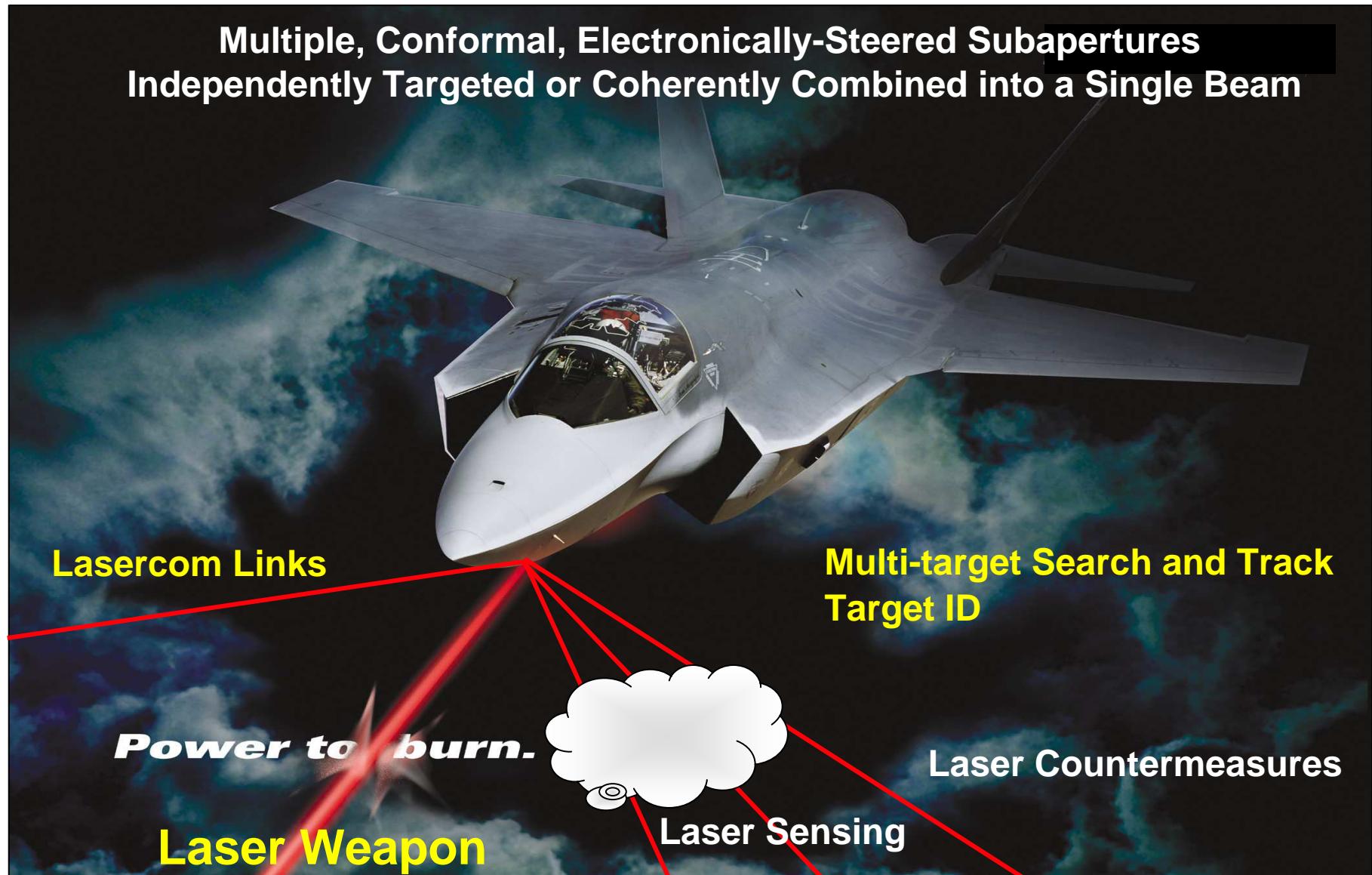


APPLE Beam Director Technology can provide:

- All-Electronic Beam Steering with 45° Field-of-Regard
- Power and Aperture Size Scaling through Coherent Beam Combining of Multiple Sub-apertures (2.5 - 5 cm dimension)
- Conformal to Most Military Platforms
 - replaces aerodynamically-challenged turret-mounted beam directors
- Near-Diffraction-Limited Beam Quality, Corrected for:
 - atmospheric turbulence — $r_o \sim 5 \text{ mm} / \text{BW}_{\text{atm}} \sim 1 \text{ kHz}$
 - aero-optic effects — $r_o \sim 5 \text{ cm} / \text{BW}_{\text{atm}} \sim 10 \text{ kHz}$

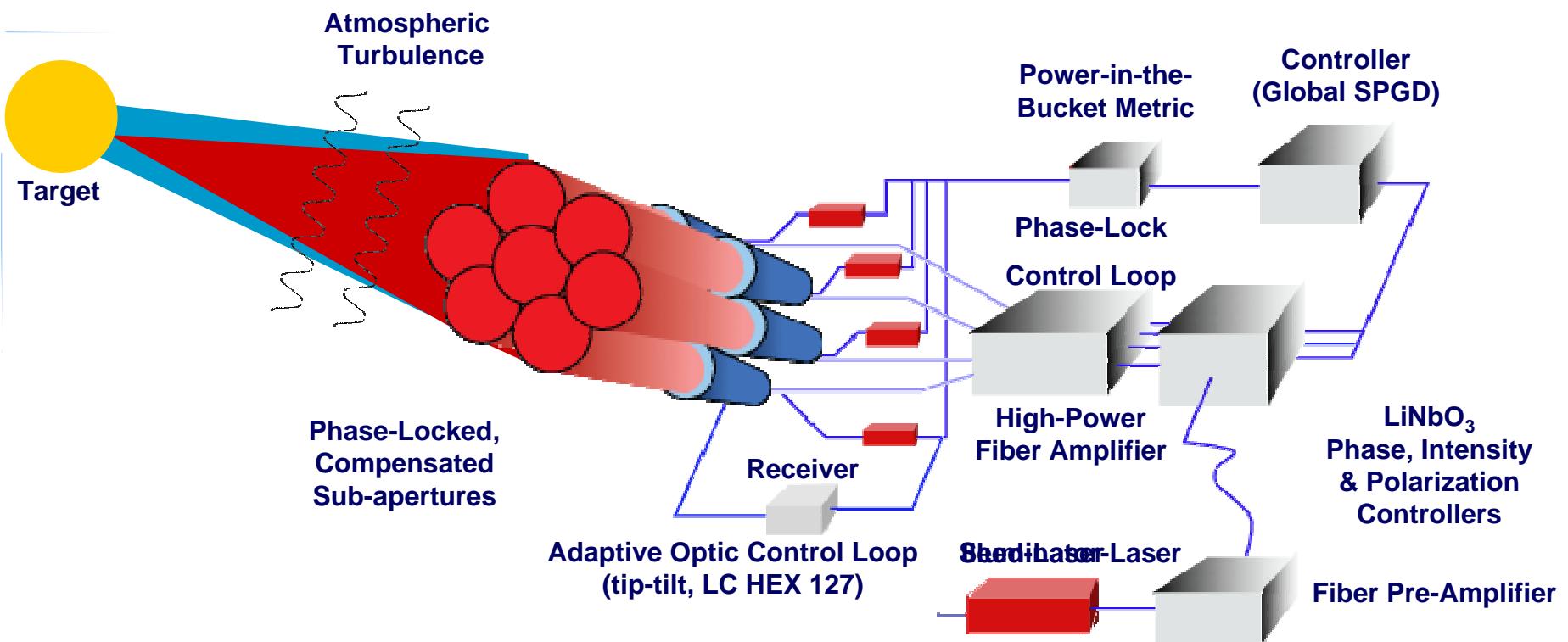
Fast, Electronically-Steered, Optical Phased Array
adaptable to essentially all DoD Laser Applications

Multiple, Conformal, Electronically-Steered Subapertures
Independently Targeted or Coherently Combined into a Single Beam



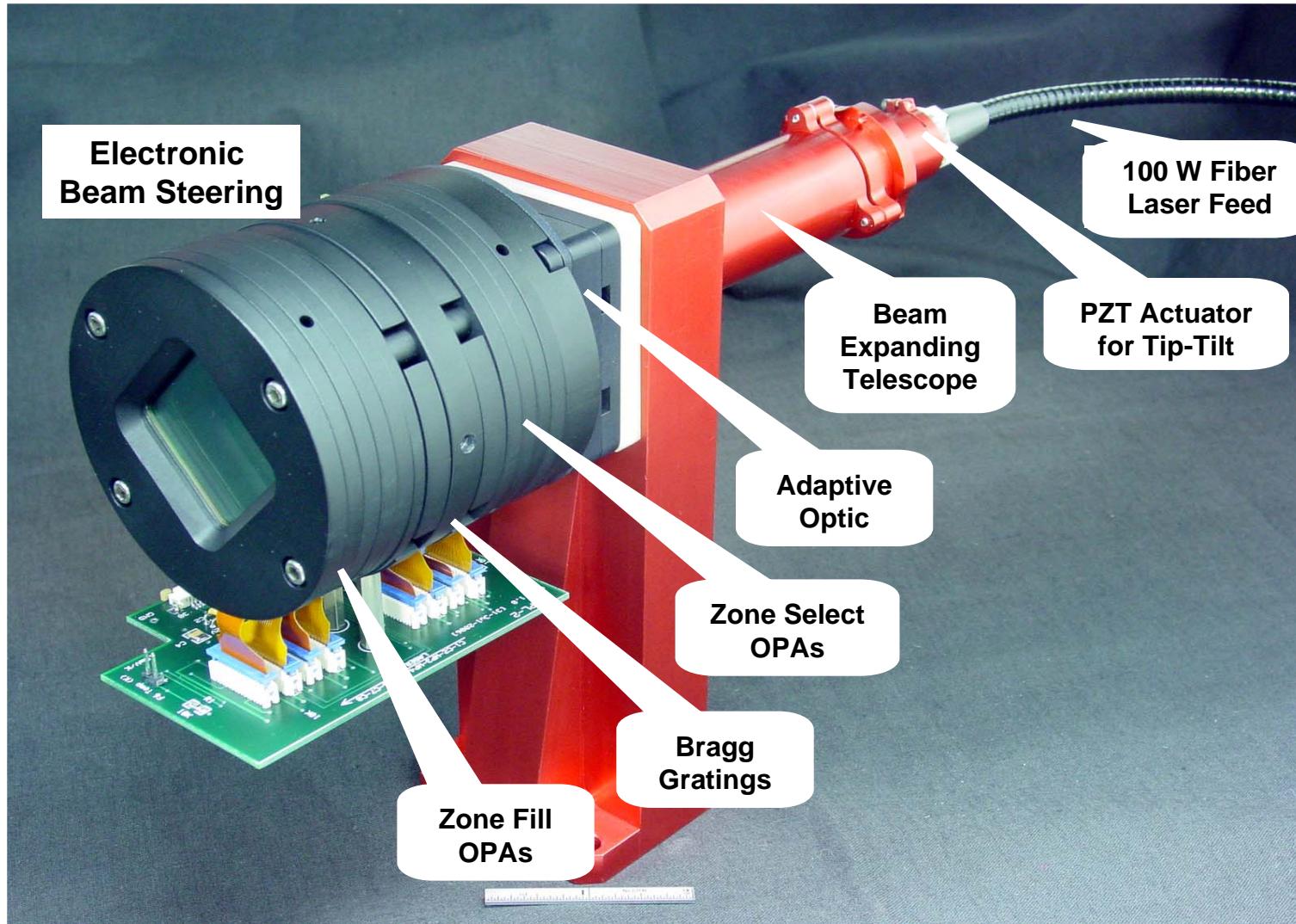


APPLE Concept





Assembled APPLE Subaperture



Challenge: Coherent Array of APPLE Subapertures with Fast Adaptive Optics

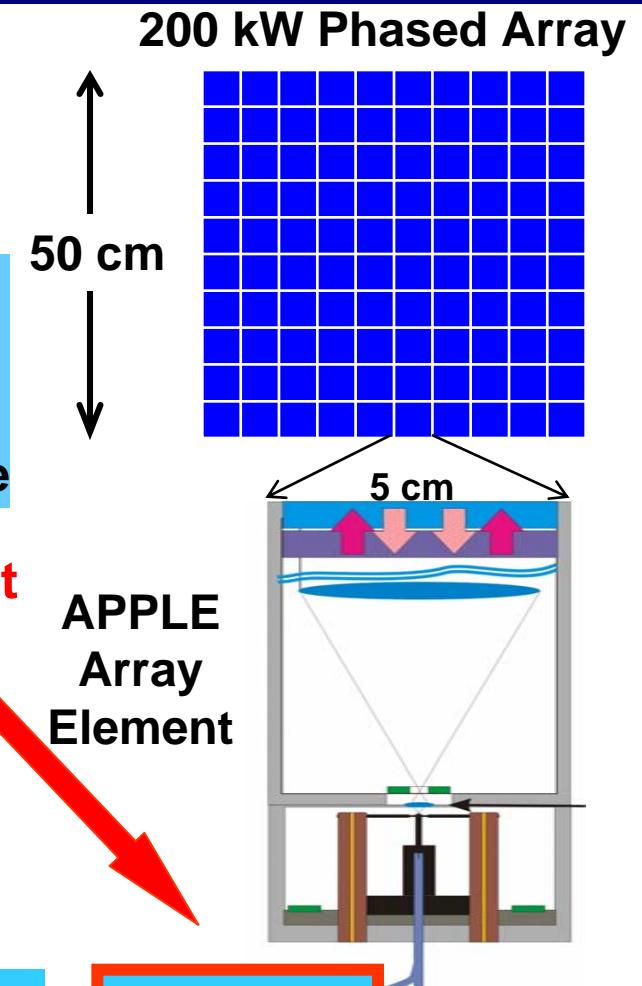
Weapon Concepts Require **Single-Mode**, **Narrowline**, Kilowatt-Class Fiber Lasers

- 100 Coherently-Combined Apertures
(10 x 10 Array)
- Need High Power Fiber Laser Amplifiers

- 2 kW
- Single Transverse Mode
- Single Polarization
- $< \lambda/20$ Phase Noise – No SBS/SRS - Narrowline

- These 2 kW Fiber Laser Amplifiers do not exist
 - 200 watts Commercially Available

**Challenge: Scale these Fiber Amplifiers
to 2 kW and Beyond**





Coherent, High Power Laser Diode Arrays



■ Why Coherent Diode Arrays?

- Electrical Efficiency
 - Thin Disk Lasers (HELLADS)
 - Fiber Lasers
 - **Coherent Laser Diode Arrays**

15%
25-30%
30-50%



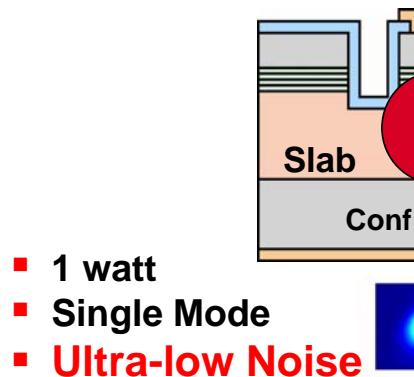
Increasing
Risk

■ Three Approaches:

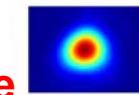
- Talbot Cavity – Spatially-Coupled Oscillators in Supermode
- Phase-Locked Loops driven from a common seed beam
- Coherent Combining with SPGD Algorithm as in APPLE

Challenge: Coherently Combine Kilowatt Laser Diode Arrays

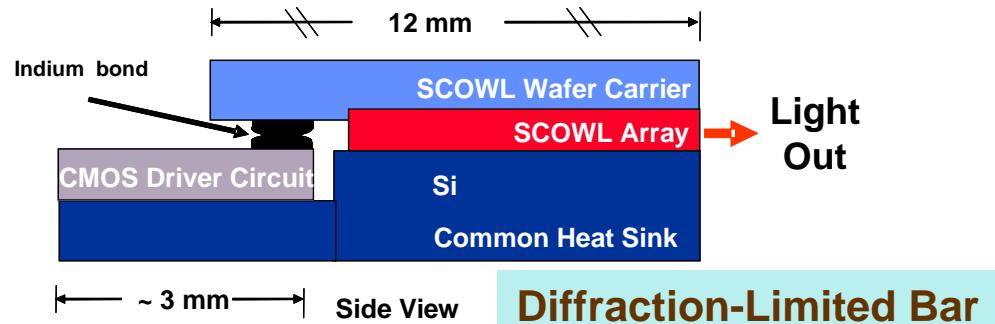
Slab-Coupled Optical Waveguide Laser (SCOWL)



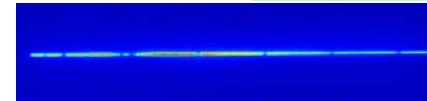
- 1 watt
- Single Mode
- Ultra-low Noise



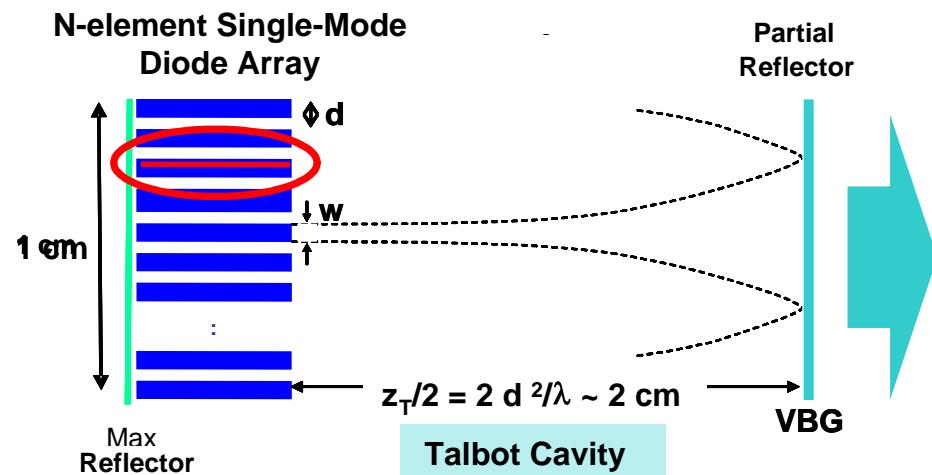
Individually drive Each Emitter in the Bar



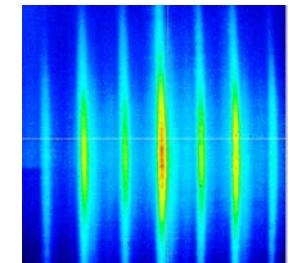
Diffraction-Limited Bar



Talbot Cavity - Laser Diode Phased Array



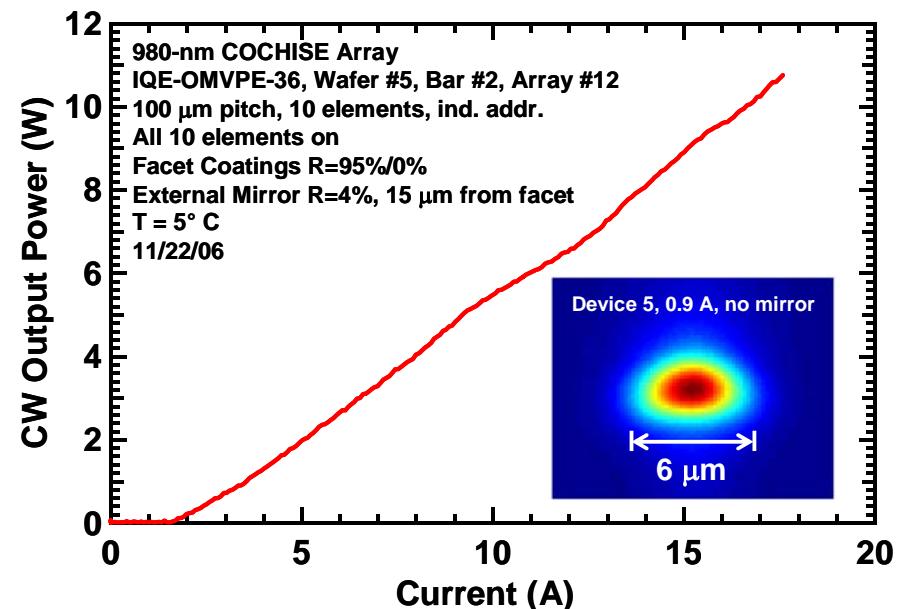
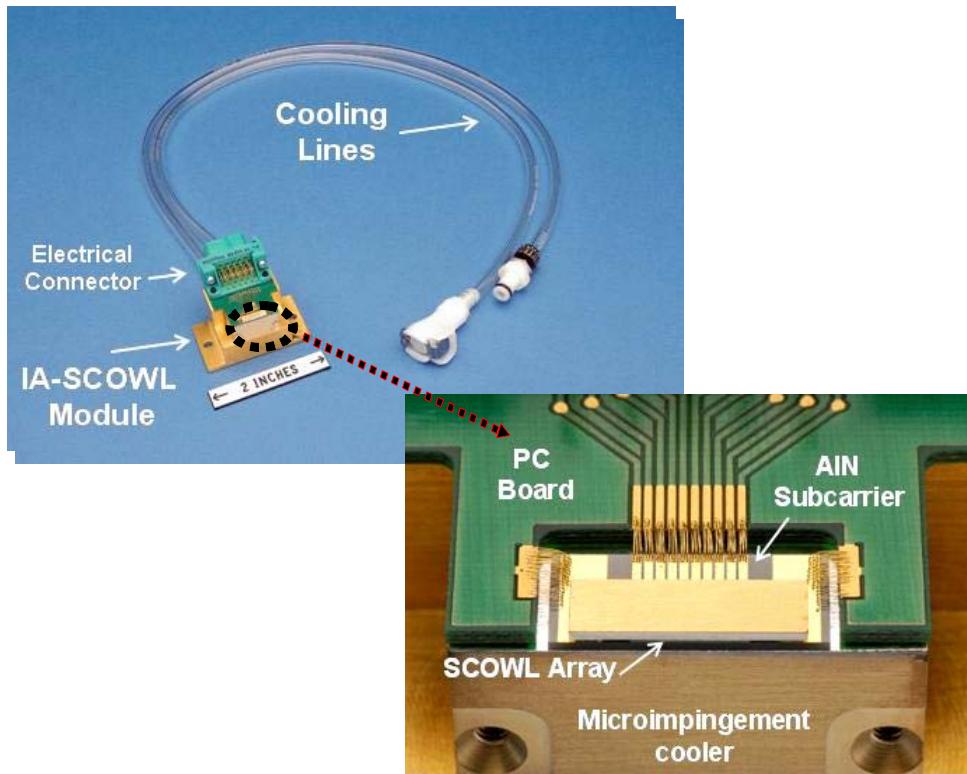
Coherent Output Beam



Remove Multi-Mode, Unphaseable
Rogue Emitters in 10s of nsec

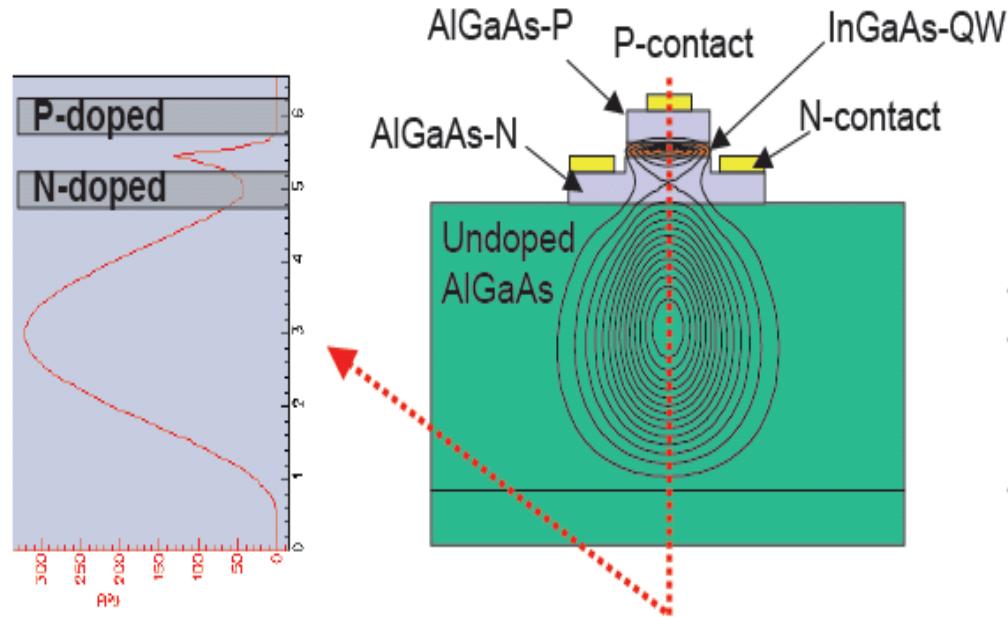
Drive each Emitter in SCOWL Bar Independently

Independent Drivers for Each Emitter in a 10-Emitter Bar



Challenge: CMOS Drivers Conformally Coupled
Directly to the Diode Bar for Current Sharing and Phase Control

Challenge: 10 watt, low noise, single-mode emitters at 50% Efficiency



Low Optical Loss

- High power
- High efficiency

Low confinement

- Stable spatial mode

Design Features

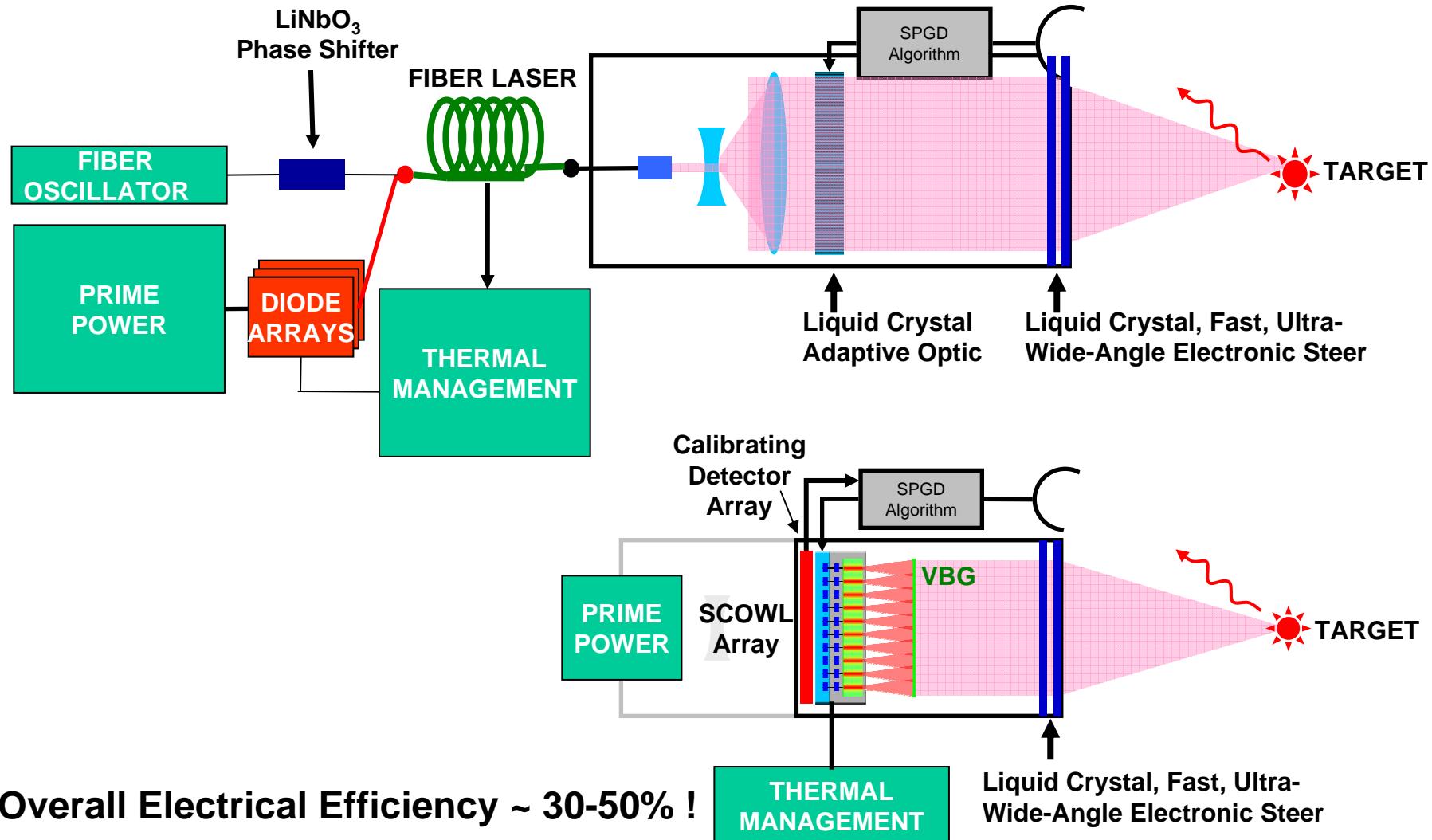
- Low modal overlap to doped layers (<0.02)
- Highly doped cladding layers ($\sim 10^{18} \text{ cm}^{-3}$)
- Thin top cladding layer ($\sim 0.05 \mu\text{m}$)
- Large optical mode ($\sim 4 \times 15 \mu\text{m}^2$)

Performance

- Very low optical internal loss ($<0.2 \text{ cm}^{-1}$)
- Very low electrical resistance, but not too low
- Very low thermal resistance ($\sim 2^\circ\text{C}/\text{watt-mm}$)



APPLE Sub-aperture driven by a Coherent Laser Dioplectic Array



Potential: 100 kW Laser Systems at 2 kilograms per kilowatt!



Additional Challenges and Areas of Interest



- **Laser Diode Technology – for pumping Thin Disk Lasers**
 - Increase SHEDS Diode Bar Power to ≥ 100 watts/bar-cm
 - Efficiency $\geq 70\%$
 - Lifetime > 1000 hours
 - 1 cm bar with 1.5 mm pitch
 - Wavelength $\sim 808\text{nm}$ (Nd:YLF or Nd:ceramic YAG Pump)
 - Thermal Resistance from Junction to Heat Sink is the limiting factor
- **Fiber Laser Technology – 100 kW**
 - Explore Ultimate Fiber Amplifier Array Scaling Limits
 - Single-Mode ($M^2 < 1.5$)
 - Single-Polarization
 - Pump Diode Brightness is the limiting factor



Some of My Current Program Responsibilities



■ Existing Programs:

- APPLE
- COCHISE
- ADHELS
- SHEDS
- Ultrabeam
- Nanowriter
- IM-VAC (DSO)
- Conformal Laser Beam Director
- Coherent Combining of Laser Diodes
- Single-Mode Laser Diode Development
- Laser Diode Reliability and Lifetime
- Laser Diode Efficiency
- X-ray Lasers
- E-Beam, Direct-Write, Maskless Lithography Tool
- Compact CT Imaging Technology for Battlefield Use

Briefed
Today

Posters

....so see Dr. John Zolper, Director of MTO now!!!
Get Recruited as a New MTO Program Manager



Back ups

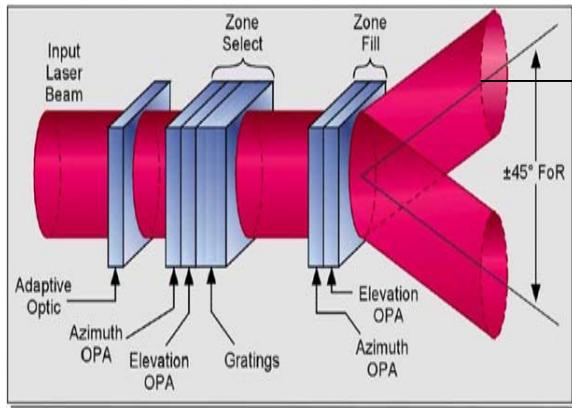




APPLET Components



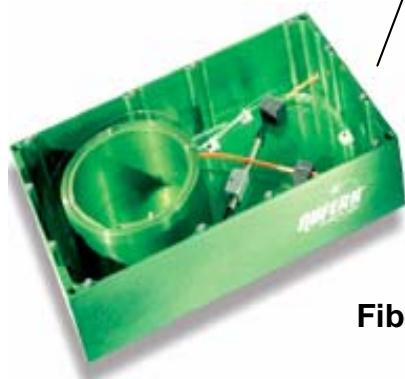
Fast Beam Steering Element



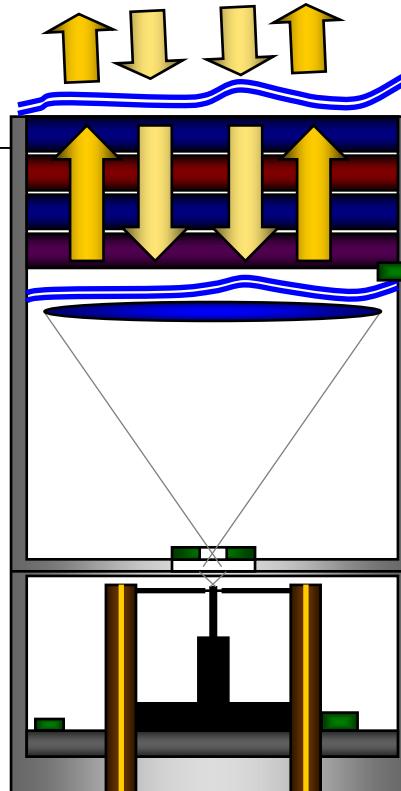
SPGD Algorithm
implemented on FPGA

LiNO₃ Electric Field Controller

- Intensity
- Phase
- Polarization

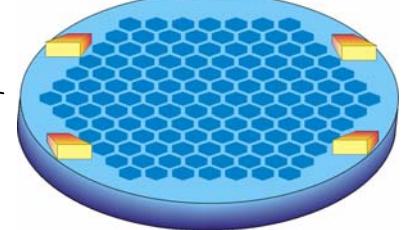


Fiber Laser Amplifier

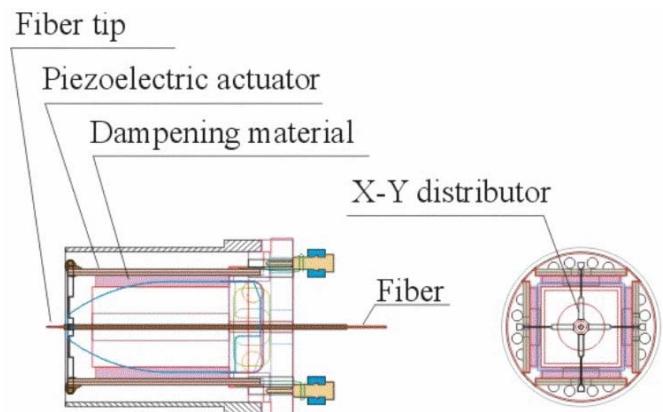


APPLET

Adaptive Optics Element
(HEX 127)



Challenge:
– 10x Faster Adaptive
Optic Elements

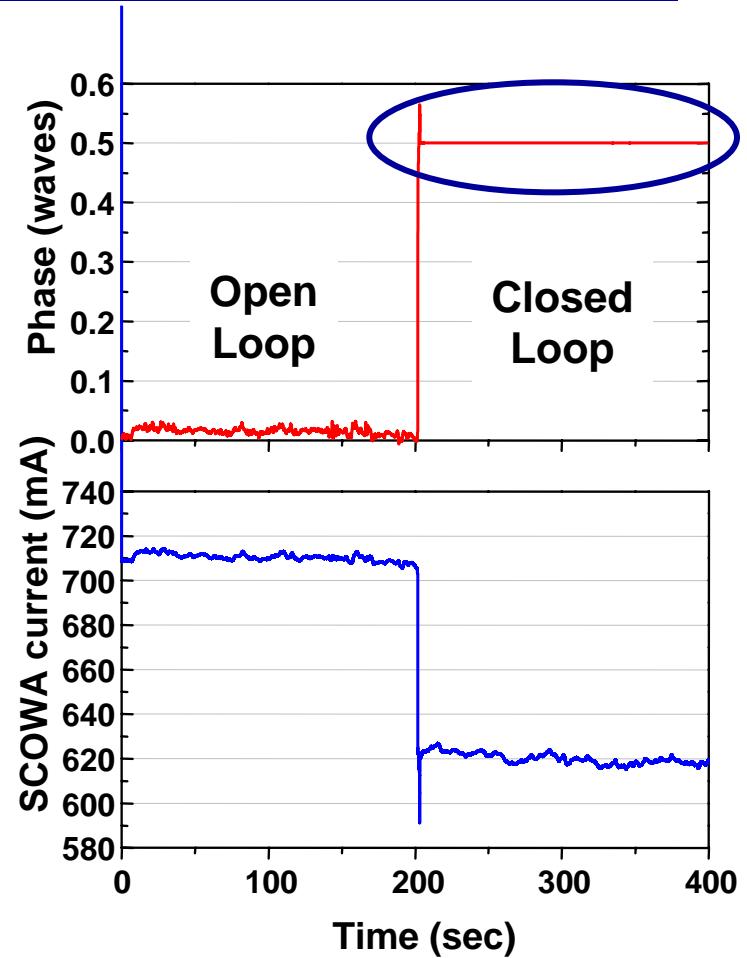
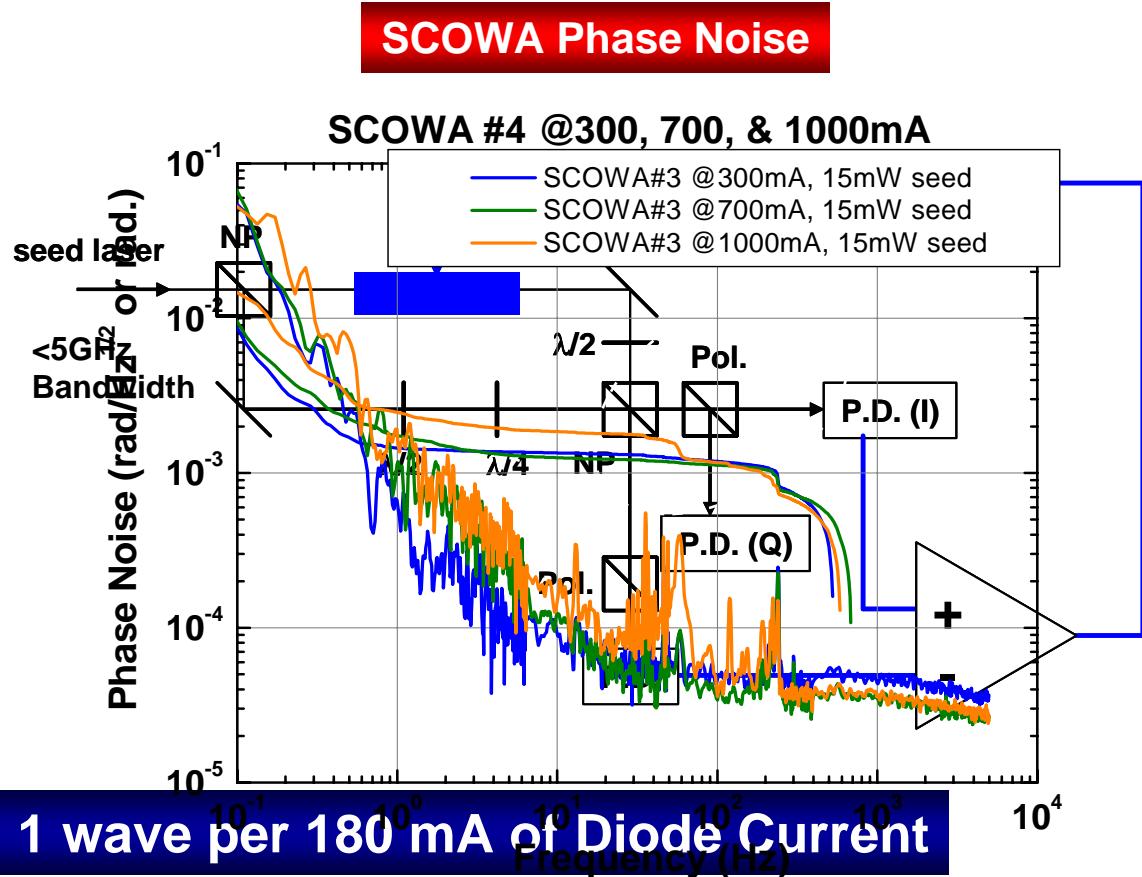


Tip/Tilt Compensator

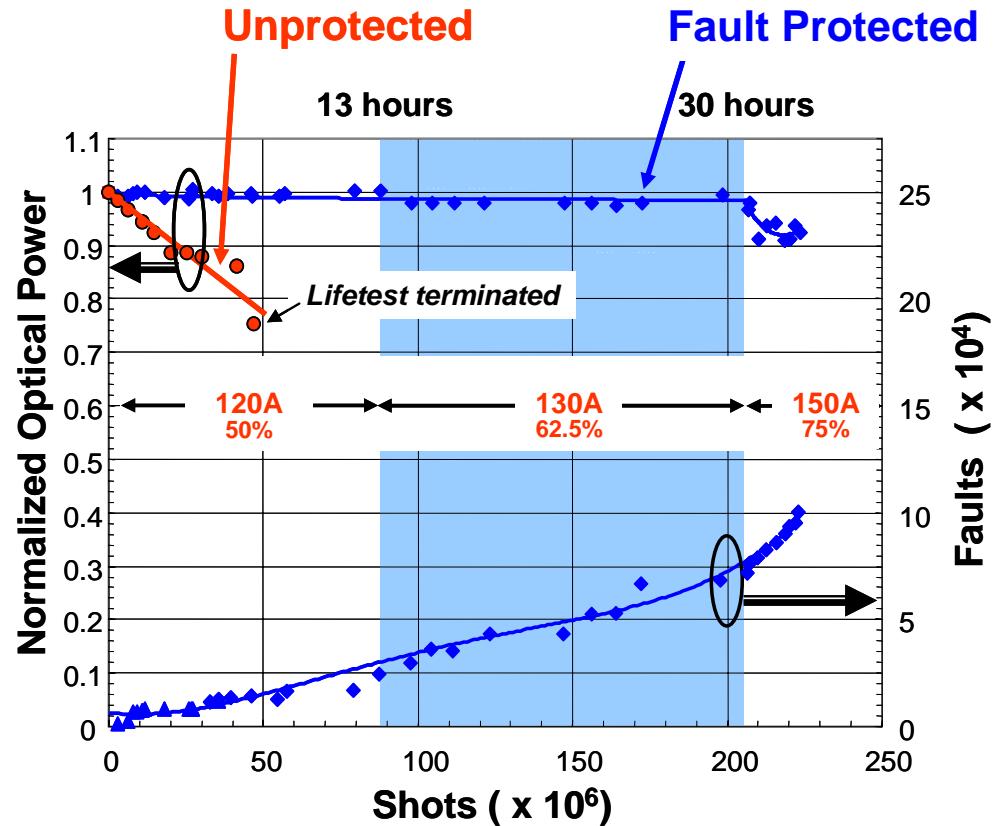
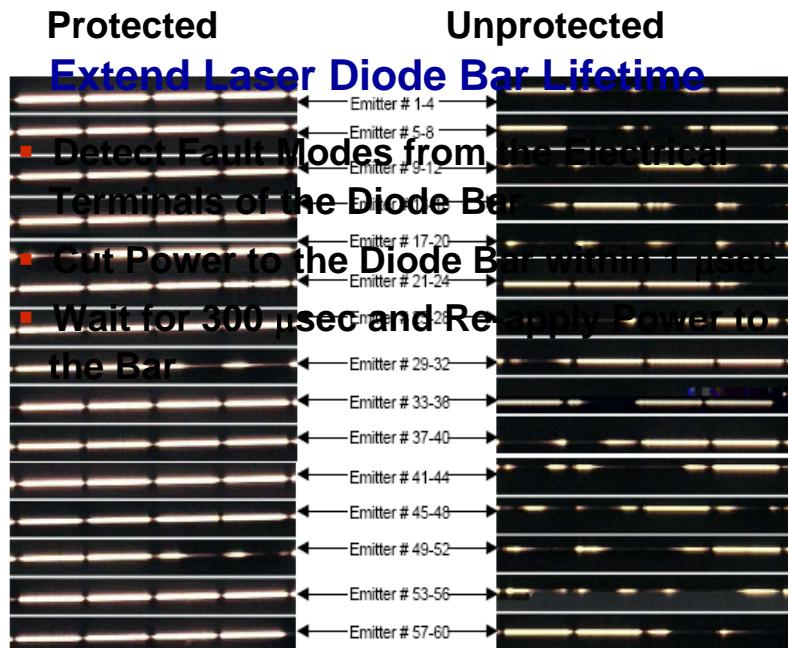


Phase-Locked Loop around a SCOWL Amplifier

Mach Zehnder Interferometer measures Phase for Feedback Control



Challenge: Coherent Array of High Power Laser Diode Amplifiers at 2 kW



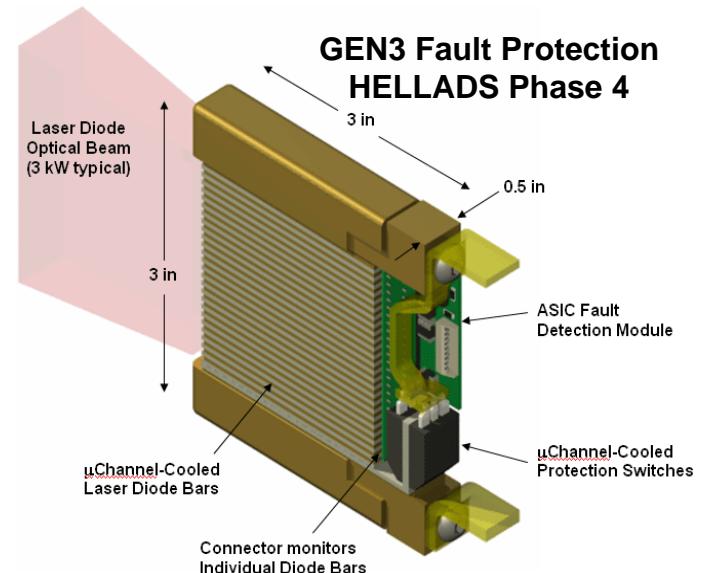
Fault Mode Frequency increases with Diode Bar Current

Eliminating Rogue Modes extends Diode Bar Lifetime by >10x
No Impact on Average Power or Efficiency

Efficiency = = **50%** \Rightarrow **70% SHEDS**

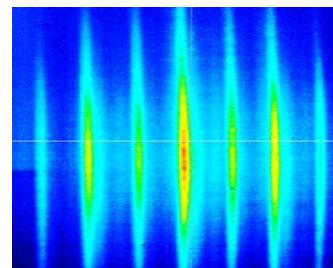
Cochise Program Goals

- **Lifetime** = **10 – 100 hours** \Rightarrow **>1000 hrs** for HELLADS and SHEDs
+
- **High Power per Bar** = **85 watts/bar** for HELLADS then **>100 watts/bar**
- **Diode Beam Quality** = **35x Diffraction Limit** \Rightarrow **< 1.4x Diffraction Limit**
+
- **Coherent Combination** = **No** \Rightarrow **Yes**



Unique COCHISE Diode Protection Extends Diode Lifetime by >10x

Brightness and Coherence





Cochise will increase Power and Safe Operating Temperature of Laser Diode Bars

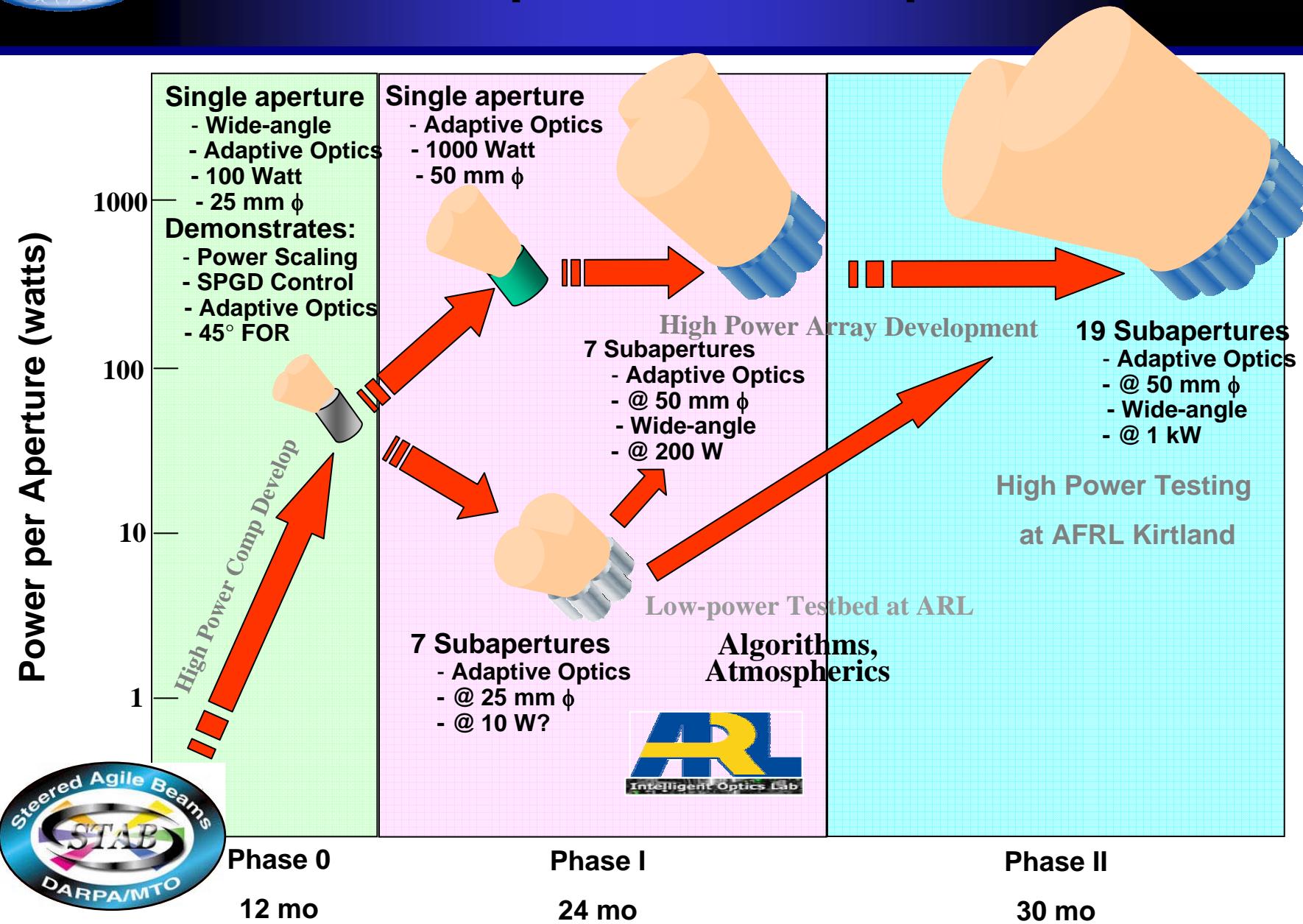


- In Year 2, COCHISE will Extend HELLADS Diode Bar Lifetime at Higher:
 - Diode Bar Power 85 Watts \Rightarrow >100 Watts
 - Inlet Coolant Temperatures 35°C \Rightarrow >50°C
- Reduce Laser Weapon System Size, Weight, and Cost
 - Impacts:
 - HELLADS Phase 4
 - DARPA Fiber Laser Program
 - All DoD Diode-Pumped Solid State Laser Programs

Challenge: 200 watts/bar-cm by Combining Diode Protection with Improved Bar Cooling Technology



Proposed Roadmap





Solid-State Laser Amplifiers

■ Challenges

- Scalability
- Efficiency
- Beam Quality/Coherence
- Size, Weight, Power

■ Programs

- HELLADS (TTO)
- HPFL (TTO)
- ADHELS/COCHISE

■ Technologies

- Thin Disks
- Fiber
- Coherent Diode Arrays

Beam Directors

■ Challenges

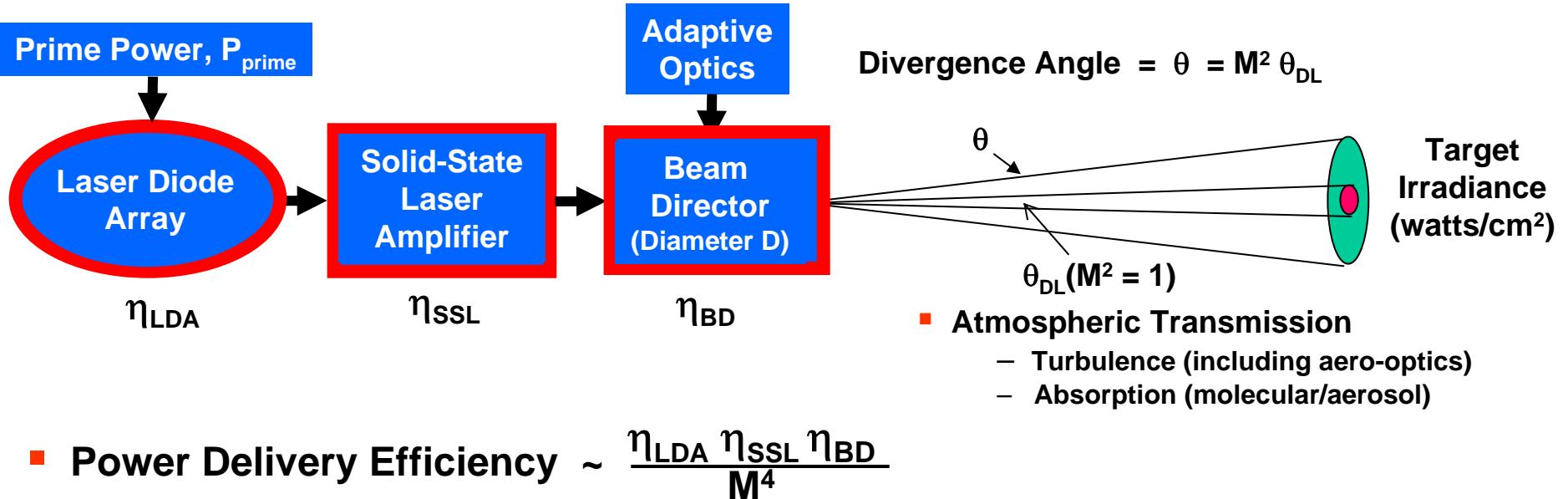
- Efficient
- All-Electronic Steering
- Scalable to High Power and Aperture Size
- Conformal to Platform
- Minimum Size/Weight

■ Program

- APPLE

■ Technologies

- Conformal Phased Array
- Risley Prisms
- Gimbaled



- Challenges
 - Power
 - Efficiency
 - Beam Quality
 - Size and Weight
 - Lifetime/Reliability
 - Electronically-steered, Conformal Optical Phased Arrays with AO

Beam Director – Applications

■ Program

- SEP
- AD
- AD

■ Agenda:

- APPLE Beam Directors
- COCHISE Coherent Diode Arrays
- Coherent Diode Arrays integrated with APPLE
- Challenges

ers